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RESEARCH MEMORANDUM

PRELIMINARY INDICATIONS OF THE COOLING ACHIEVED BY EJECTING WATER UPSTREAM FROM THE STAGNATION POINT OF HEMISPHERICAL, 80° CONICAL, AND FLAT-FACED NOSE SHAPES AT A STAGNATION TEMPERATURE OF 4,000° F

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PRELIMINARY INDICATIONS OF THE COOLING ACHIEVED BY EJECTING WATER UPSTREAM FROM THE STAGNATION POINT OF HEMISPHERICAL, 80° CONICAL, AND FLAT-FACED NOSE SHAPES AT A STAGNATION TEMPERATURE OF 4,000° F

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SUMMARY

A preliminary investigation of the effectiveness of water-vaporization cooling that would be obtained by ejecting water upstream from the stagnation point was conducted in a liquid-fuel rocket jet at a stagnation temperature of 4,000° F. Measured temperature-time histories were obtained for several water flow rates and for zero flow rate for hemispherical, 80° total angle conical, and flat-faced nose shapes. For all the water-ejection tests, a water-vapor shroud was formed over the nose shapes of the models. No damage occurred to the nose shapes when cooled, but all the models when not cooled ignited and sustained considerable damage.

INTRODUCTION

The development of long-range ballistic missiles and the constantly increasing flight speeds of other types of flight vehicles requires that the vehicle structure be capable of maintaining its integrity for stagnation temperatures that may be several times greater than the operating limit of conventional structural materials. The destructive effects of aerodynamic heating for stagnation temperatures comparable to a flight Mach number of 7.0 have been indicated in reference 1 where, in hot-air jet tests, copper and stainless-steel models were melted in slightly less than 12 seconds. It is very apparent that considerable effort must be expended towards investigating and developing workable heat-alleviation schemes.

A research program having this purpose has been initiated by the Pilotless Aircraft Research Division of the Langley Laboratory. One phase of this program has been the development and investigation of a

scheme whereby test models were cooled through blocking of the heat input by means of a water-vapor shroud which formed over the nose shapes of the test models. The water-vapor shroud was formed by ejecting water upstream, from the stagnation points of the test models, into the exhaust stream of a liquid-fuel rocket motor at a jet stagnation temperature of approximately 4,000° F. The free-stream Reynolds numbers per foot were approximately 800,000. Measured temperature-time histories were obtained for several water flow rates and for zero flow rate for hemispherical, 80° total angle conical, and flat-faced nose shapes.

SYMBOLS

A_{jet}	cross-sectional area of jet, sq ft
A_{model}	model frontal area, sq ft
G_c	water flow rate, lb/sec
$\dot{m}$	jet weight flow rate, lb/sec
M_∞	free-stream Mach number
R_∞	free-stream Reynolds number per foot
T_c	incoming coolant temperature, $^\circ F$
T_t	jet stagnation temperature, $^\circ F$
T_w	model inside surface temperature, $^\circ F$
F	flow-rate parameter as defined by equation (1)

TEST APPARATUS AND PROCEDURE

The Langley supersonic chemical jet, which is shown in figure 1, was utilized for the present tests. This facility is a liquid-fuel rocket motor that uses red fuming nitric acid and anhydrous ammonia as fuels. Measurements of fuel flow rate, thrust, and chamber pressure provide the necessary data for calculating the jet stagnation temperature. The nozzle is 2.5 inches in diameter and has a design Mach number of 3.0.

The geometry of the test models is shown in figure 2. The models, constructed from 347 stainless-steel, were a hemispherical nose shape, an 80° total angle conical nose shape, and a flat-faced nose shape. Water was ejected upstream through tubes located at the stagnation points of the models. The water-flow rates were obtained from calibration measurements which were made for each model. Temperature measurements were obtained from No. 30 gage chromel-alumel thermocouples spot-welded to the inside surfaces of the models at the locations shown in figure 2. The incoming coolant temperature was measured by means of a thermometer inserted into the water storage tank. A pressure gage allowed observation of the water-supply tank pressure. When this pressure became constant, the model was injected into the jet stream, the jet flow conditions being constant at this time.

The coolant flow rates of the present tests were the lowest for which a continuous coolant flow rate could be achieved with the available regulating system. When the storage tank pressure was lowered just slightly, the surface temperature of the models, observed through a visual recorder, began to fluctuate and indicated an intermittent coolant flow. An additional very slight lowering of the tank pressure resulted in the temperature of the cooled model behaving the same as the temperature of the uncooled model. The pressure difference between steady and intermittent temperatures was less than one-half pound per square inch. Since this value was equal to the reading accuracy of the water tank gage, the intermittent coolant flow rate resulted from insufficient control of the water flow.

Preliminary tests were made with the flat-faced and hemispherical nose shapes for a 1/16-inch inner-diameter ejection tube. The minimum flow rates obtained for these models were high. Changing the ejection tube inside diameter to 1/32 inch enabled much lower flow rates to be achieved.

RESULTS AND DISCUSSION

The test Mach number, the calculated stagnation temperature T_t, and the measured values for the incoming coolant temperature T_c, the water flow rate in pounds per second G_c, the weight flow rate of the jet in pounds per second $\dot{m}$, and the inner diameter of the ejection tubes for the present tests are given in table I. The free-stream Reynolds number per foot was approximately 800,000 for all the tests.

In figure 3, there is shown the measured temperature-time histories of the three models for various values of the flow-rate parameter F.

The values of F were calculated from

$$F = \frac{G_c A_{jet}}{\dot{m} A_{model}} \tag{1}$$

For the present tests, A_{model} was considered to be the model frontal area. The curves for F equal to zero are the measured temperature-time histories for no cooling. In all the tests, the temperatures of the cooled models, at the locations shown in figure 2, quickly reached and maintained a level considerably lower than that for the uncooled models for the total time of the test run of 10 seconds.

Examination of the color movies taken during the test runs indicated that, for all the tests made with the hemispherical nose shape where the tube extended upstream from the face, including a preliminary run where the coolant flow rate was intermittent, there was no visual indication of discoloration of the tube surface.

The color movies showed clearly for all the tests where constant coolant flow rates were obtained, a definite water-vapor shroud formed over the nose shapes of the models. In figures 4 and 5, there are shown enlargements taken from the movies of the tests. These enlargements are for times of 1.0 and 10.0 seconds after the test models had been injected into the jet stream. There is no visible damage to the cooled models at either of the times, but the uncooled models sustained considerable damage by 10 seconds. Examination of the cooled models after each run showed no visible damage to the models or ejection tubes.

Order-of-magnitude calculations of the cooling efficiency of this type of system indicate that, although the three nose shapes were cooled to essentially the same order of surface temperature (320° F to 470° F), the efficiency of the 80° conical nose shape cooling system was higher than that of the flat-face and hemispherical nose shapes. As indicated in figure 3, the heat input to the uncooled conical model, at the time where the inner surface temperature of the uncooled model is the same as the equilibrium temperature of the cooled model, was slightly more than four times that of the other two uncooled models. In blocking the heat input to an area equal to the projected frontal area of the models, the water ejected upstream from the conical nose shape would be completely vaporized. For the flat-faced and hemispherical nose shapes, however, the heat input would be absorbed by the water ejected upstream being raised only to saturation temperature. Since temperature measurements were taken at only one location on each nose shape (see fig. 2), the actual extent of the cooled area is not known; thus the comparison

between the three nose shapes applies only to the actual thermocouple locations of these tests. Because of this limitation an exact evaluation of the cooling efficiencies cannot be made. The results, however, do indicate that this relatively simple system of cooling can be effective, particularly, when utilizing the heat of vaporization of the ejected water.

CONCLUDING REMARKS

A preliminary investigation of the effectiveness of water-vaporization cooling that would be obtained by ejecting water upstream from the stagnation point was conducted in a liquid-fuel rocket jet at a stagnation temperature of 4,000° F. Evaluation of the test results indicates that the method is effective in cooling the test models and can substantially utilize the heat absorption capacity of water being vaporized. Based on these results, it can be concluded that the method of cooling is promising and merits additional research.

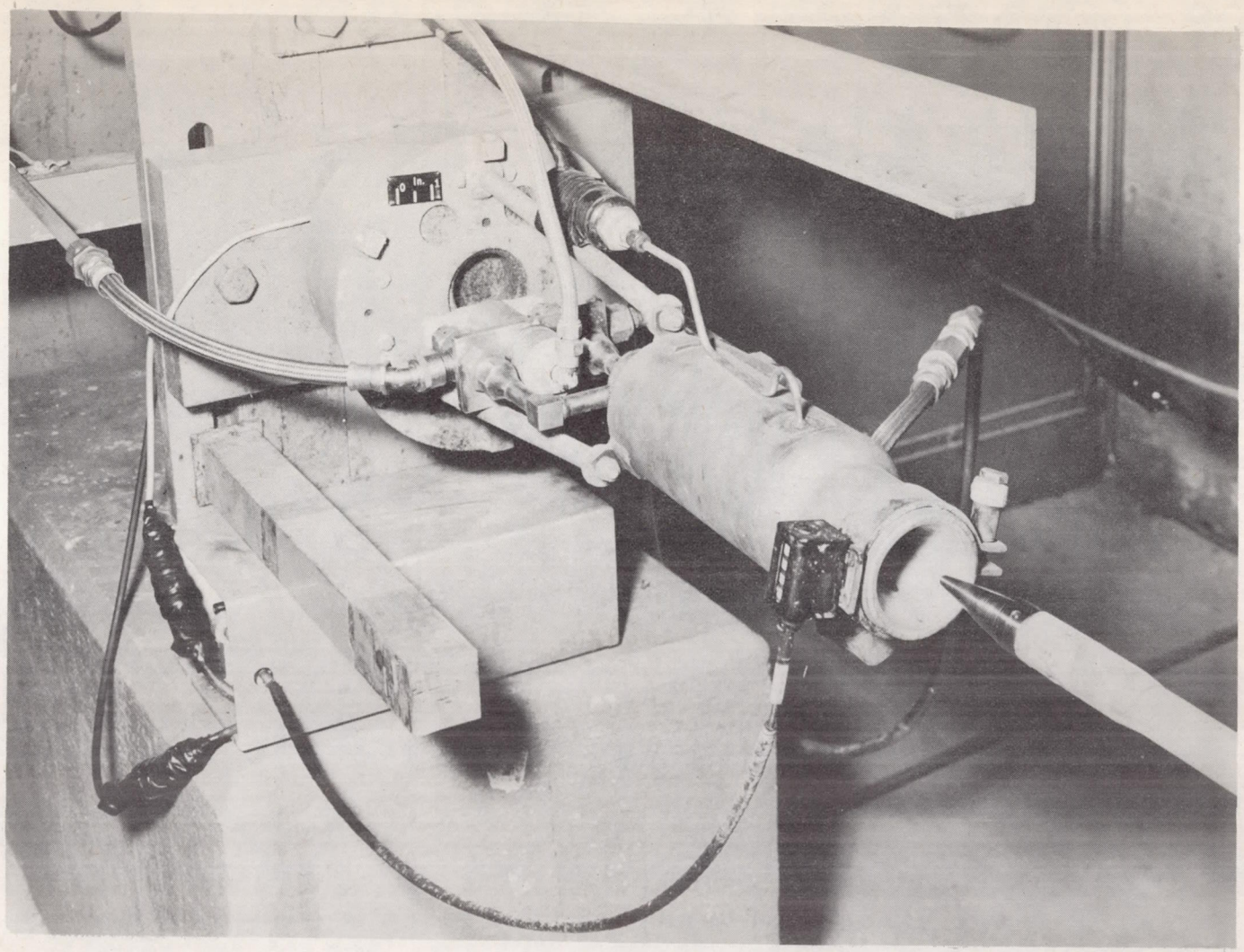
Langley Aeronautical Laboratory,
National Advisory Committee for Aeronautics,
Langley Field, Va., August 16, 1957.

REFERENCE

1. Purser, Paul E., and Hopko, Russell N.: Exploratory Materials and Missile-Nose-Shape Tests in a 4,000° F Supersonic Air Jet. NACA RM L56J09, 1956.

TABLE I.- TEST CONDITIONS

Nose shape	M_∞	T_t, °F	T_c, °F	G_c, lb/sec	$\dot{m}$, lb/sec	Coolant tube inside diameter, in.
Hemispherical	2.89	3,800	51	0.011	0.971	1/32
		3,800	--	0	.955	----
80° conical	2.88	3,900	60	0.0068	0.981	1/16
		3,900	--	0	.973	----
Flat-faced	2.86	4,000	64	0.0080	0.967	1/32
		4,000	--	0	.974	----



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Figure 1.- Photograph of the Langley supersonic chemical jet.

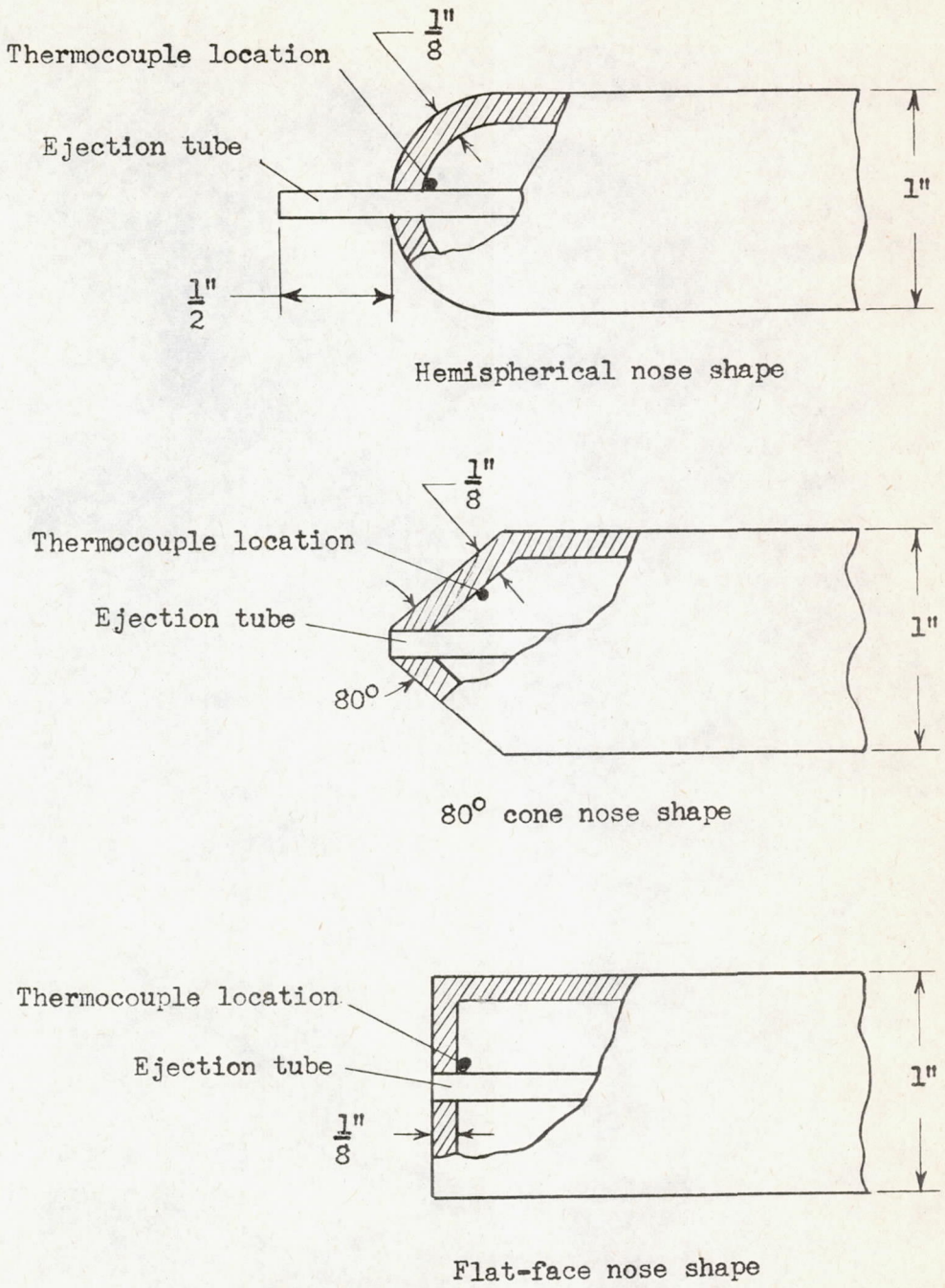


Figure 2.- Stainless-steel test models.

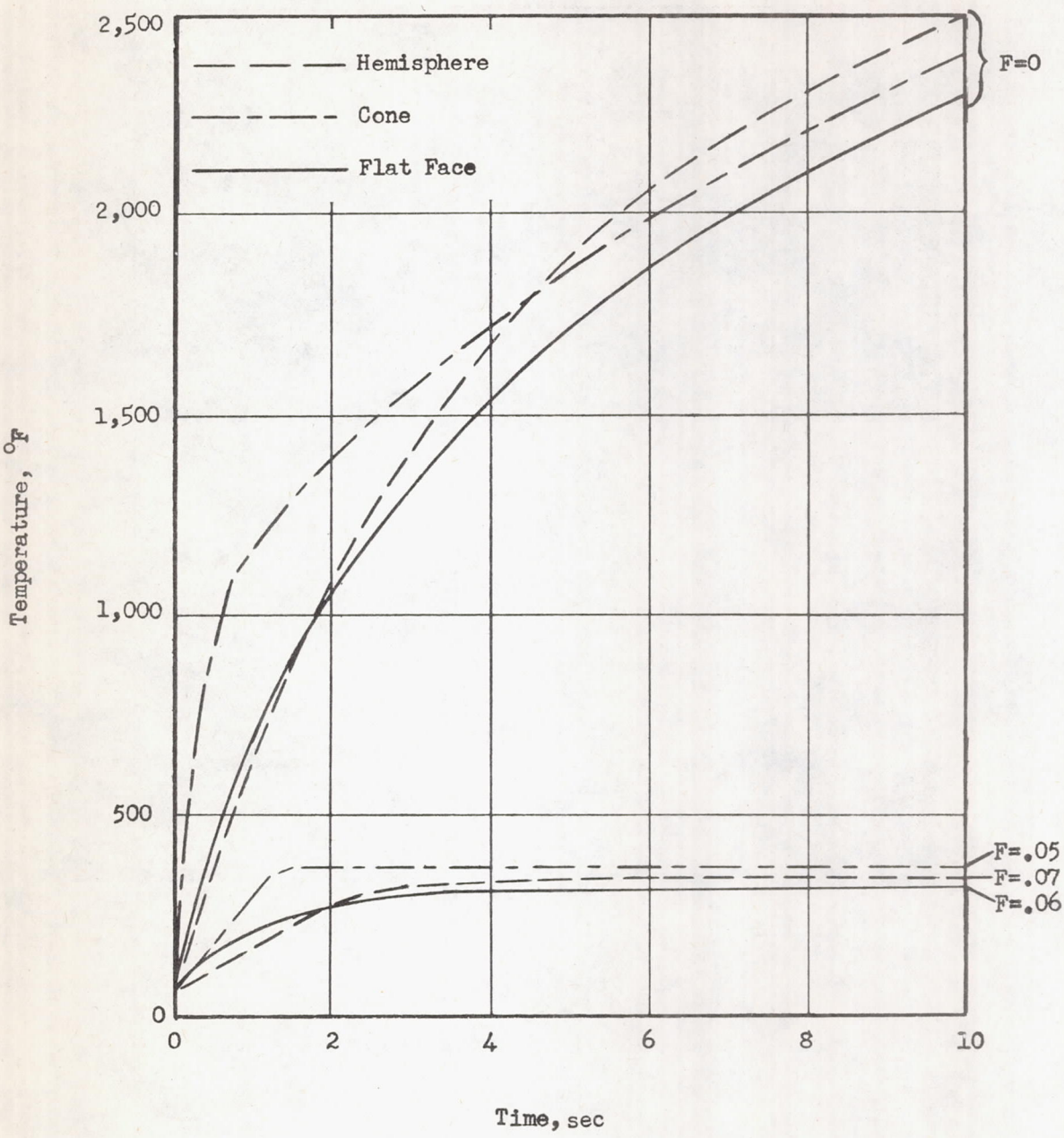
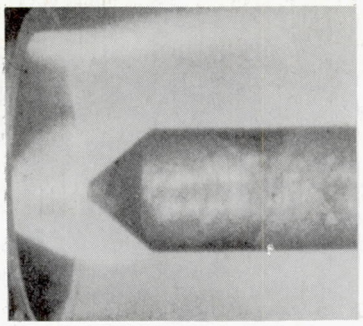
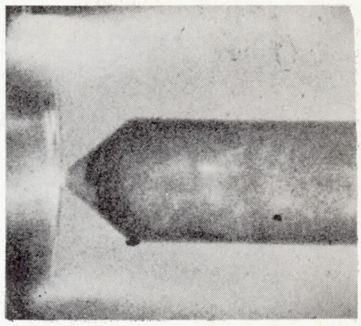


Figure 3.- Measured temperature-time histories for various values of the flow-rate parameter F.

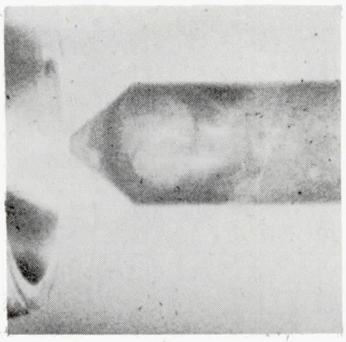


Cooled

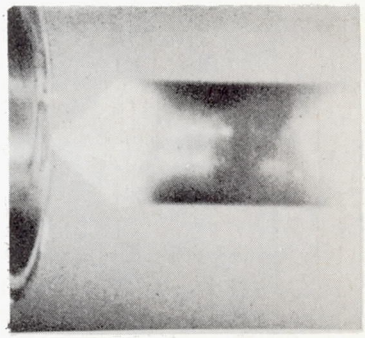


Uncooled

(a) t = 1 second.



Cooled

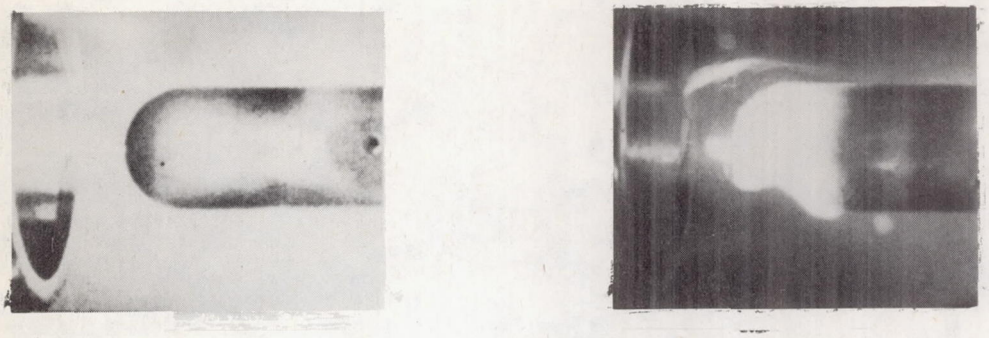


Uncooled

(b) t = 10 seconds.

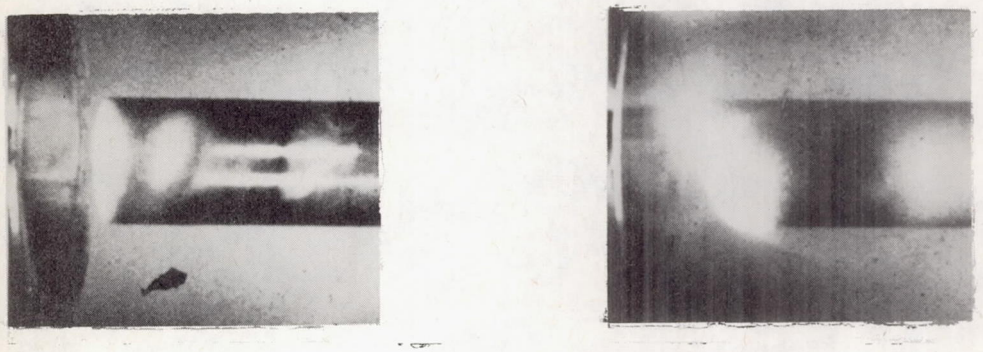
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Figure 4.- Comparison of 80° conical nose shape cooled and uncooled models. Zero time refers to the time when models are centered in jet.



Cooled Uncooled

(a) Hemispherical nose shape.



Cooled Uncooled

(b) Flat-faced nose shape.

Figure 5.- Comparison of cooled and uncooled hemispherical and flat-faced nose shape models 10 seconds after models are centered in jet.